 J Hum Ecol, 46(2): 165-176 (2014)

Morphometric Factors Influencing Settlements in the Lesser Himalayas: A Case Study of the Dhundsir Gad, a Tributary of the Alaknanda River

Hari Ballabh[*], Srinivasan Pillay and Viratha Hariram

School of Agriculture, Earth and Environmental Sciences, University of KwaZulu-Natal, Westville Campus, Durban 4000, South Africa

KEYWORDS Himalayas. Drainage Network. Landscape Attributes. Settlements. Environmental Forcing

ABSTRACT Dhundsir Gad, a tributary of the Alaknanda River, in the Lesser Himalayas of India is a small but important mountain watershed. The watershed possesses a myriad of geomorphic landforms that affect construction of settlements. Settlements are usually chosen based on environmental and economic benefits. In the Himalayan Mountains, this is not always achieved due to the high potential for natural hazards, particularly flash flooding and mass wasting. The Dhunsir Gad watershed was separated into three zones based on settlement density and altitude. Within each zone, key geomorphic and anthropogenic factors (climate, geology, landforms, slope character, drainage character, relief and landuse) that influenced settlement location were identified. Watershed analyses were carried out using topographical maps, aerial photographs and satellite imagery. Field surveys were also conducted to gather data on settlements and to verify map data. The mid-valley zone was found to be the most favorable for the location, containing 18 settlements (82%) and was probably a compromise between relative safety and environmental benefits. As a consequence of adverse environmental conditions only two settlements were found above 1600 m and below 1000 m altitudes. The study showed that mountain inhabitants optimized settlement locations based on changing geomorphology and natural hazards.

INTRODUCTION

Physical environmental conditions have important and multi-faceted influences upon human settlements and other land uses. The physical environment is a composite of a multitude of factors which include geology and soils, vegetation, weather and climate, water (Silbernagel et al. 1997) (availability, consistency of supply and quality) and, geomorphological attributes. Their influence upon settlement choice is not always direct, but depends upon and is influenced by the individual's or society's perception of the physical environment and its physical attributes. The choice of settlement location and land utilization can be considered one of the most prominent compromises of all physical and human factors in an area (Prasad 1988). However, only a portion of the perceived total environment affects decision-making and influences behavioral patterns as expressed, for example, in the setting of settlements and the use of land for subsistence agriculture. Human behavior does not only affect the physical environment, such as in the decision to clear a forest, but also influences the way in which the physical environment is perceived. Continuous reappraisal follows initial decisions as environmental and socio-cultural conditions change and is thus integral to successful human occupation and use of an area (Wagstaff 1973). Past human-environment interactions have been the focus of several studies (Guo et al. 2014; Kuper and Kropelin 2006; Gupta 2004; Mo et al. 1996). Changes of environmental conditions such as climate, landscapes and hydrology have affected settlements as well as the rise and fall of cultures (Guo et al. 2014; Hodell et al. 1995; Dodonov et al. 2007; Turney and Brown 2007). However, considerable difficulty exists in accurately defining relationships between settlements and the surrounding environment due to the lack of high resolution environmental archives or archaeological data (Geo et al. 2014). On the other hand, several authors have critically addressed the nature of prediction in geosciences and geological engineering with special reference to the associations between human behavior and fluvial geomorphology (Oreskes et al. 1994). Opportunities for sustaining human beings and establishing eco-friendly environments within a

Address for correspondence:
Dr. Hari Ballabh
School of Agriculture, Earth and Environmental Sciences,
University of KwaZulu-Natal,
Westville Campus, Durban 4000,
South Africa

landscape can be studied by examining socio-economic and landform processes. In such studies, it is important to recognize that landscape properties are also modified due to ecological processes which, in turn, influence physical as well as cultural processes.

Efforts by researchers to understand and interpret the linkages between settlement location decisions and the array of opportunities or difficulties presented by the natural environment have focused largely on the latter. For instance, climate change and environmental catastrophes such as earthquakes, floods and volcanoes were often invoked to explain changes of culture, social complexity and human settlement patterns (Kaniewski et al. 2008; Staubwasser and Weiss 2006; Brooks 2006; Haug et al. 2003; Berberian and Yeats 2001). This is especially true of early geographers who sought to firstly map the physical environment together with its geomorphological attributes. Settlements were then envisaged as having developed at specific locations where key resources such as water and food were most accessible. However, there have been instances where researchers have overlooked the geomorphological landscape attributes that collectively prompted or aided location decisions. At best, these linkages were examined only in a cursory manner.

Landform mapping is possible with the help of an array of aids: field surveys, aerial photographs, topographical maps and satellite imagery. The approaches used by Wooldridge (1932) and Unstead (1933) came to light in Australia with the publication by the Common Wealth Scientific Industrial Research Organization (CSIRO) (Christain and Steward 1964).

In India, mapping techniques based on morphometric techniques were adopted by Wooldridge (1932) followed by Kharkwal (1967) and Asthana (1967), in Banaras Hindu University, Varanasi. With the use of large scale photography, Datt (1983) carried out geomorphological mapping techniques of the Bino Basin in the Uttarakhand Himalaya. Datt (1991) also summarized local definitions of landforms, land systems, land use patterns and natural hazards. Based on earlier work, landform analyses were adopted and expanded to other parts of the Indian Himalaya by a plethora of researchers. In landform analysis, the basic descriptive unit is the land system, which can be defined as "an area or group of areas where the pattern of topography, soil and vegetation can be recognized (Christian and Stewart 1964).

Using the land system as a basis for classification, one can map assemblages with various geomorphological attributes. The classification can then be expanded to include social and cultural parameters that form the basis for studying the relationships between natural environmental attributes and socio-cultural behavior. This in turn would serve to provide some insight into the primary factors affecting decisions of where to settle. The focus of this study was to examine the linkages between landscape attributes and settlements in a region highly susceptible to natural environmental forcing. In this study, settlements and their characteristics together with the physical attributes of the landscape of the Dhundsir Gad, a watershed of the Lesser Himalayas, were mapped using geomorphological attributes. This data, coupled with socio-cultural information garnered from interview surveys was utilized to relate settlements and their characteristics to the physical environment in the Dhundsir watershed of the Himalayas. This study therefore presents an integrative study of landscape attributes and human settlements.

Study Area

The study area was the watershed of the Dhundsir Gad, a sub-catchment of the Alaknanda Basin in the lower Himalayas, Uttarakhand State and covering a geographical area of approximately 50.5 km^2 (Fig. 1). Geographically, the study area is located between 30˚13' to 30˚23' N and 78˚44' to 78˚49' E and administratively, it falls within the jurisdiction of the Tehri District of the state of Uttarakhand.

The altitude of the basin ranges from 520 m to 2360 m over a horizontal distance of approximately 15 km creating a steeply rising, rapidly flowing river. The rapid altitudinal changes affects local climate creating distinct sub-tropical, temperate and sub temperate climate zones.

The 'Dhundsir Gad' is a fifth order tributary of the River Alaknanda and rises from the Maniknath hill range in the north at the height of 2360 m. The Dhundsir Gad follows a fairly steep gradient before joining the Alaknanda River at an elevation of 520 m near Dhundprayag. Tola Gad, Negail Gad and Udiyar Gad are the main tributaries of the Dhundsir Gad (Fig.1). The climate of the study area is sub-tropical and average annual rainfall varies from 1000 – 1500 mm.

Geologically, the Dhundsir Gad watershed is developed across the North Almora Thrust (NAT) which passes through from NW to SE

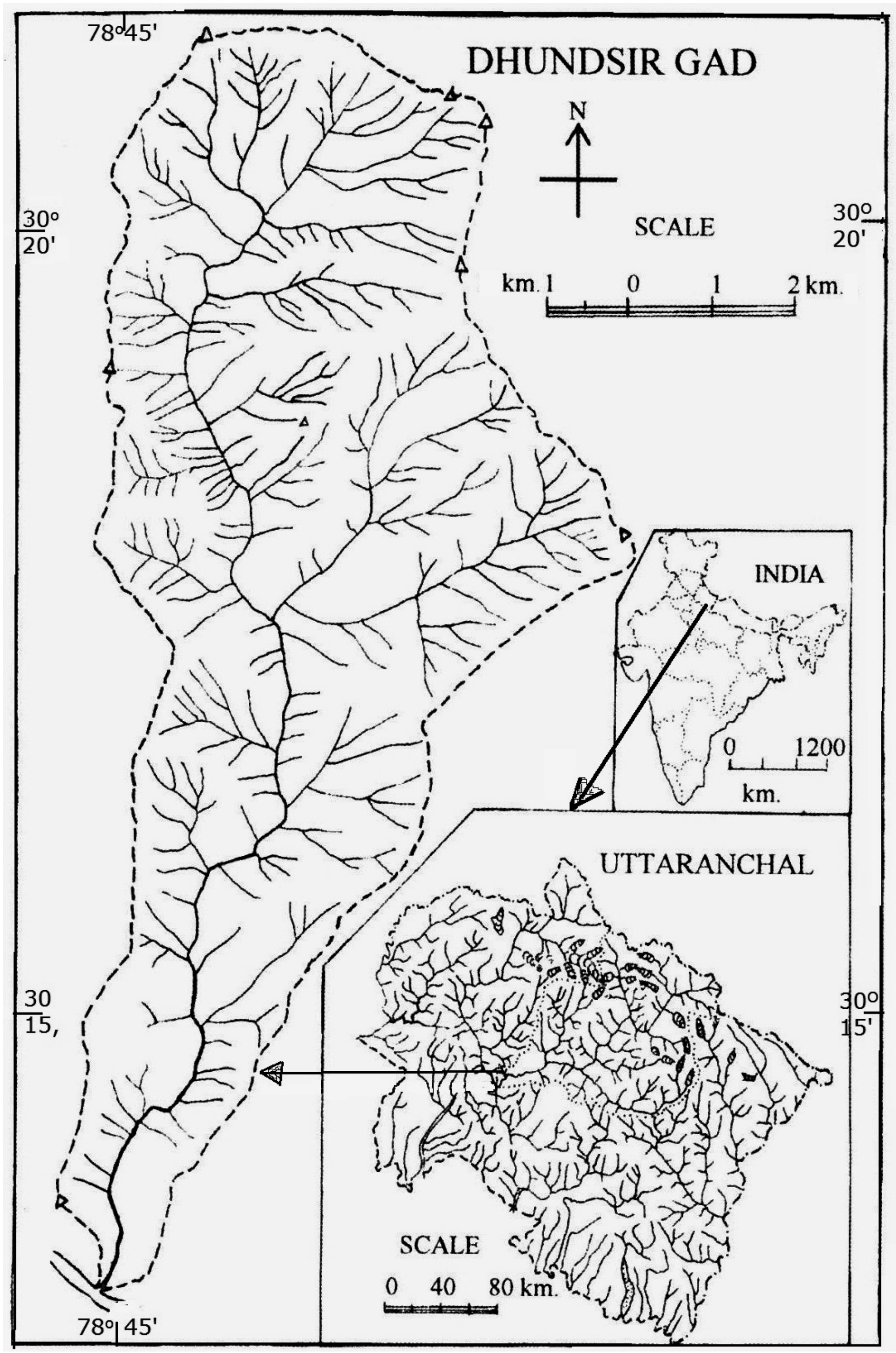

Fig. 1. Location of the study area

across the Dhunsir Gad watershed and separates two tectonic units with steeply dipping rocks: the Garhwal Group of rocks consisting of the Sandra, Deoban and Damta formations and, the Chandpur Group comprising of ferruginous quartzite, phyllite, slate and dolomitic limestone rocks (Saklani 1971; Mehdi et al. 1972; Sandaliya 1984) (Fig. 2). Arrenceous, carbonaceous and micaceous phyllitic rocks are well exposed in the study area. Foliation and laminations are well developed in the phyllite. The drainage pattern of the watershed is structurally controlled by a large number of folds, fractures, faults, lineaments and joints which are characteristic of these rock formations.

The soils in the Dhundsir Gad basin have been almost entirely derived from the decomposition of the quartzitic, gneissic and phyllite lithological parent material hence they vary in their relative fertility. The soil profile as such depends upon the slope, vegetation cover and, landuse condition of the area.

Historically, this area is recognized as one of the holy places of Uttarakhand, namely, *Dhundprayag*. There are 22 villages in the watershed with 1302 households. The greater concentration of population is found between 1000 m and 1600 m above sea level while a smaller settlement inhabits the lower altitudinal zones because of deep and narrow valleys.

METHODOLOGY

In this study, attempts were made to explore the process of adjustment of human and cultural forces over the physical environment in the form of settlements and associated spatial imprints.

To investigate these relationships, the study area was divided into three morphogenetic units based on altitude. These are the lower valley zone extending to a maximum altitude of 1000 m; the mid-valley and scarp zone ranging between 1000 m and 1600 m and the high ranges and scarp zone with altitudes exceeding 1600 m. These subdivisions were based on the predominance of morphological/ morphogenetic features (Table 1) and settlement density.

Landform mapping was facilitated with the help of Survey of India topographical sheets (No. 53J/15, 16) and satellite data sourced from Google Earth®. A systematic grid framework (1 km x 1 km) was superimposed over the mapped area and within each cell a database of the morphogenetic and cultural aspects of the micro-area was developed from map and satellite imagery. Concurrently, a detailed geomorphic survey was carried out through a series of longitudinal and transverse field traverses to validate map extracted data. The dominant morphogenetic characteristics of the study area were then allocated to each of the grid cells which were then merged to create a series of composite maps of morphological characteristics using appropriate geomorphic symbols.

A complete survey of 22 settlements and land use characteristics of the study area were subsequently carried out. Following a settlement count from satellite images, a questionnaire survey of springs of the villages in each settlement was undertaken. For each settlement, dwellings chosen for interviews were randomly selected by using a random number generator and a map of the dwelling distribution for each settlement. The parameters that were investigated and data generated are presented in Table 1.

RESULTS AND DISCUSSION

The study area was subdivided into three morphogenetic units, the lower valleys (LV), the mid-valleys (MV) and the high ranges (HR) as shown in Table 1. These divisions were based principally on settlement frequency and further characterized in terms of morphogenetic, climate, vegetation and anthropogenic characteristics. The LV zones were dominated by steep ‘V’-shaped valleys, gorges and interlocking spurs in fluvially dynamic environments. Frequent flooding and landslides in this zone make settlement hazardous (Fig. 3). Similarly, the HR above 1600 m altitude presents major environmental challenges for settlements, such as steep slopes, poor soil development and adverse climatic conditions. The bulk of the settlements in the Dhundsir Gad catchment were found in the MV zone lying between 1000 m and 1600 m. Figure 2 is a composite longitudinal cross-sectional terrain profile of the Dhunsir Gad watershed showing ecological, topographical, geological and landuse characteristics. The concentration of settlements and agriculture in the mid-valley is clearly evident, as is the general paucity of land utilization in the high ranges and the low valley zones.

Table 1: Classification of morphogenetic and morphometric units in the Dhundsir Gad watershed

Morphogenetic units	*Lower valley (LV)*	*Mid-valley (MV)*	*High ranges (HR)*
Altitude	*>-1000*	*1000-1600*	*>- 1600*
	Morphogenetic Characteristics		
Area in km^2 (%)	9.21 (18.24)	17.73 (35.11)	23.56 (46.65)
Landforms	'V' shaped valley, gorges, interlocking spurs, rapids	Scarps , convex slopes, water divides and colluvial, fans river terraces	Summits, Saddles water divides, scarps and planner surfaces; Questa
Dominant geology	Phyllite	Quartzite	Biotite Gneiss
	Climatic Characteristics		
Climatic zone	Sub-tropical	Temperate	Sub- temperate
Average temperature (°C)	High(20-22)	Moderate(15-20)	Low (10-15)
Average rain fall (mm)	<-1000	1000 - 1500	> 1500
Landuse	Scrub and bushes	Pine forest, cultivation and cultivation in valley sides	Oak forest and grazing land and cultivation in lower reaches
	Morphometric Characteristics		
Dominant slope (°)	15° to 25°	10°-20°	20°-30°
Slope aspect	E-SW-SE	NW-SE-SW	NW-S-SE
Drainage density (length of streams km/km^2)	1-3	2-4	2-5
Drainage frequency (No. of junctions /Km^2)	5-8	0-11	5-11
Relative relief (%)	800-1600	1600-2000	1800-2000
Confluence density (no. of	stream junctions /km^2)	6-9	3-9 (0-6)
Dissection index	0.25 -0.30	0.20-0.30	<- 0.20
	Anthropogenic Characteristics		
Total village	2(9%)	18. (82%)	2 (9%)
Size (km^2)	1.450 (8.06%)	14.722 (81.89%)	1.807 (10.05%)
Agriculture area under irrigation (km^2)	0.009	1.171	0.229
Agriculture area un-irrigated(km^2)	0.615	5.147	0.719
Total agriculture	0.624 (8.00%)	6.318 (80.00%)	0.947 (12.00%)
No. of households	64 (4.92%)	1055 (81.03%)	183 (14.06%)

Source: Primary survey

Dominant Geology and Geomorphology

Gneissic Terrain

The gneissic terrain at the HR zone is generally a gentle slope near the ridges. A uniform pattern of the landforms has developed in this region due to similar geological setup and erosion processes. Planner surfaces are found along the ridge of the Gaddikhal range and are used for grazing while the ridges themselves are under oak forest. The valley floors have accumulations of colluvial fan deposits which are used for cultivation. The area above 1600 m elevation is the headwater zone and receives high rainfall. The lower reaches of this zone, adjacent to the MV is also the most inhabited. In this zone, the water flow rate is higher with low sedimentation due to the steep gradient.

Quartzite Terrain

Most of the MV is underlain by quartzite terrain with a small strip of limestone outcrop (Fig. 2) and some metabasics between Dungrivaha and Phayalgaon. The Phayalgaon area is

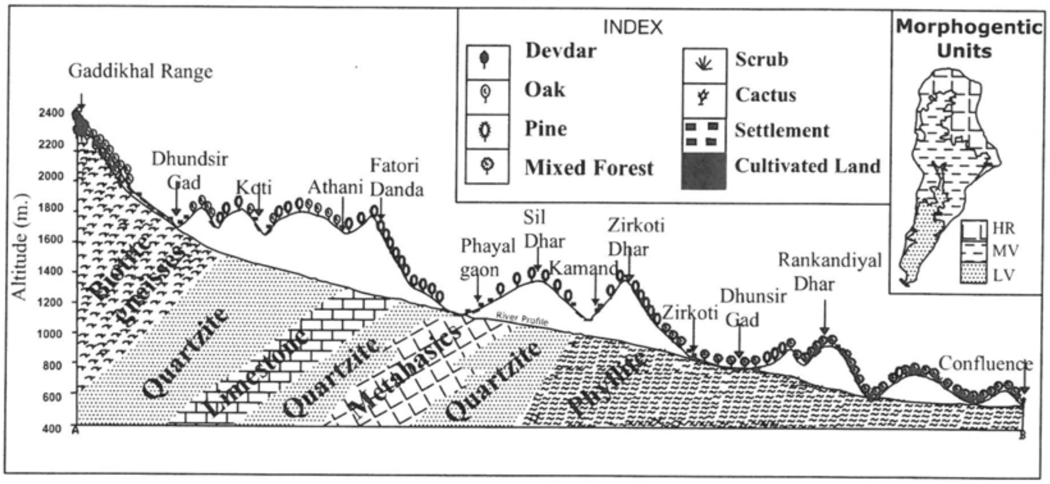

Fig. 2. Longitudinal geoecological and land use cross-sectional profile of Dhundsir Gad

the most tectonically disturbed zone. Here, north-south, north west-south east and north east-south west lineaments meet each other (Ballabh 2008). Therefore, the valley widens considerably in this part of the catchment. The repeated phases of deformation are reflected in the evolution of a plethora of geomorphic landforms including knick points, fault lines, river terraces, gorges, rapids and drainage anomalies (Ballabh et al. 2011). A deep, steep sided gorge (76 m) is developed on metabasic rocks downstream of Phayalgaon. Upstream of this gorge are well marked interlocking spurs. At Khark, there are two sets of river terraces whilst near Shivalaya, the river flows in a narrow valley on unevenly dissected limestone terrain (Ballabh 2008).

The quartzite terrain is dominated by steeper north facing escarpments with a greater hazard potential. Old landslide debris, avalanches, scree cones, talus cones and rock fall features are very common here. The hill tops and ridges are conical, asymmetrical and have a high drainage density (Table 1; Fig. 5). Geo-hydrologically, this zone has the most potential for generating water discharge following precipitation because the rocks are impervious in nature, slopes are moderate to steep, and infiltration capacity is low.

Phyllitic Terrain

The LV phyllitic terrain is basically pervious, weathered and dissected by denudation processes. These rocks are associated with a thrust zone and are highly deformed and easily weathered. This terrain is adversely affected by mass wasting processes of slumping, landslides and slip failures with deep stream incision. Consequently, the valley widens prominently in the thrust zone and, in part of the phyllitic terrain, the deep incision of the river has created a gorge. Four well developed sets of river terraces occur near Dang village (Fig. 4) and, several geomorphic features: faults, river avulsion, relict meanders and high level terraces are found near the confluence of the Dhundsir Gad with the Alaknanda River. The steep slopes and propensity for natural hazards make this zone un-favorable for settlement.

Morphometric Attributes and Settlements

The location of settlements was studied in relation to the landscape's morphological characteristics and climatic conditions (Table 1; Fig. 5). Climatologically, the most favorable locational zone is the MV where temperatures are moderate and good rainfalls of 1000-1500 mm are received. The LV experiences a colder, drier climate which, coupled with the steep terrain, precludes the development of settlements.

Slope angle is an important controlling factor for settlements in any area. In the Dhundsir Gad watershed, steep slopes are common in the LV zone as well as the HR zone, leaving the MV, where over 80% of the settlements are located, as the most favourable zone (Table 1; Fig. 2; Fig. 5). The

MV also recorded the lowest drainage density of the three zones (2-4 km/km^2). This fact, coupled with the moderate drainage frequency and confluence density together with a relatively low dissection index (Fig. 5), implies that this zone has more contiguous land units, making them more suitable for cultivation. Further, much of the agricultural land of the MV (> 80%) does not require irrigation.

The composite set of positive natural morphogenetic factors of the MV zone would have presented the most viable options for settlement locations at the time of habitation. This is evidenced by the majority of settlements (> 80%) being located in this zone. The other two zones each had 9 % of settlements. Over one thousand households are located at various sites of the MV compared to less than 250 for the other two zones combined (Table 1). The higher population of the former means that the landscape is more intensively and extensively used for the dominant activities of the region: livestock farming, agriculture and establishment of dwellings.

The distribution of agricultural land in relation to settlement location shows that the largest area of cultivated lands lies in close proximity to the greatest concentration of settlements, all of which are in MV zone. From Table 1, it can be seen that the maximum number of settlements are located on the south-eastern (SE) and north-western (NW) slope aspect which receive greater daily sunlight hours (Fig. 5). This is also an important consideration for the location of agricultural fields.

Relief and Settlement

Quantitatively, absolute relief and settlements demonstrates a negative relationship in dicating poor association with increasing height, as indicated in Table 1 and Figure 5. In this study, settlements and population density in the LV is low due to the steep slopes and relatively high vulnerability to mass movements, especially landslides in this dominantly phyllitic terrain. Table 1 shows a well-marked concentration of settlements in the 1000 m to1600 m altitude group. This range covers 81.89% of the total settlements and 35.11% of the watershed, whereas only 2 villages (9% of total settlements) are located in the high altitude zone (>1600 m) even though this zone covers 23.56% area of the watershed.

Drainage Density, Drainage Frequency and Settlements

The drainage density in the Dhunsir Gad valley varies from below 1 km to above 4 km length of stream per km^2 of land (Fig. 5; Table 1). Maximum settlement concentration occurs in the area of moderate to high drainage density, again in the central part of the watershed. Areas of low drainage density and hill top regions of the watershed have generally been avoided for settlement development.

Springs and Settlements

A total of 79 springs were identified and mapped in the Dhundsir Gad watershed. Thirty-nine of the 79 springs in the area are used for potable and domestic water uses and 19 of these springs for irrigation purposes. In the study area the density of springs was directly related with settlement density. In fact, every settlement has at least one spring within the village or at close proximity to the village. Generally, these springs are utilized for irrigation and drinking purposes by the villagers and, according to the local people, have served as focal points for the location of settlements and cultivated fields in the past. Therefore, the presence of springs has had an influence on where settlements were located in the past. The presence of springs wouldno longer serve as a pivotal factor in selection of location sites for settlements with the recent advent of piped water to the villages.

Landuse and Settlements

The main occupation of the Himalayan people is agriculture supplemented by livestock farming. In the case of the study area, the villageslocated in the higher altitude areas have greater access to agricultural and forest land compared to lower altitude villages. In the MV zone, the availability of water for irrigation is greater than that at the high altitude zone.

Forest Land and Settlements

Forests in this area are generally found between 900-1800 m on the northern slopes, and shrubs mostly at lower elevations. The distribution of forested patches increases from east to west and similarly from south to north in the

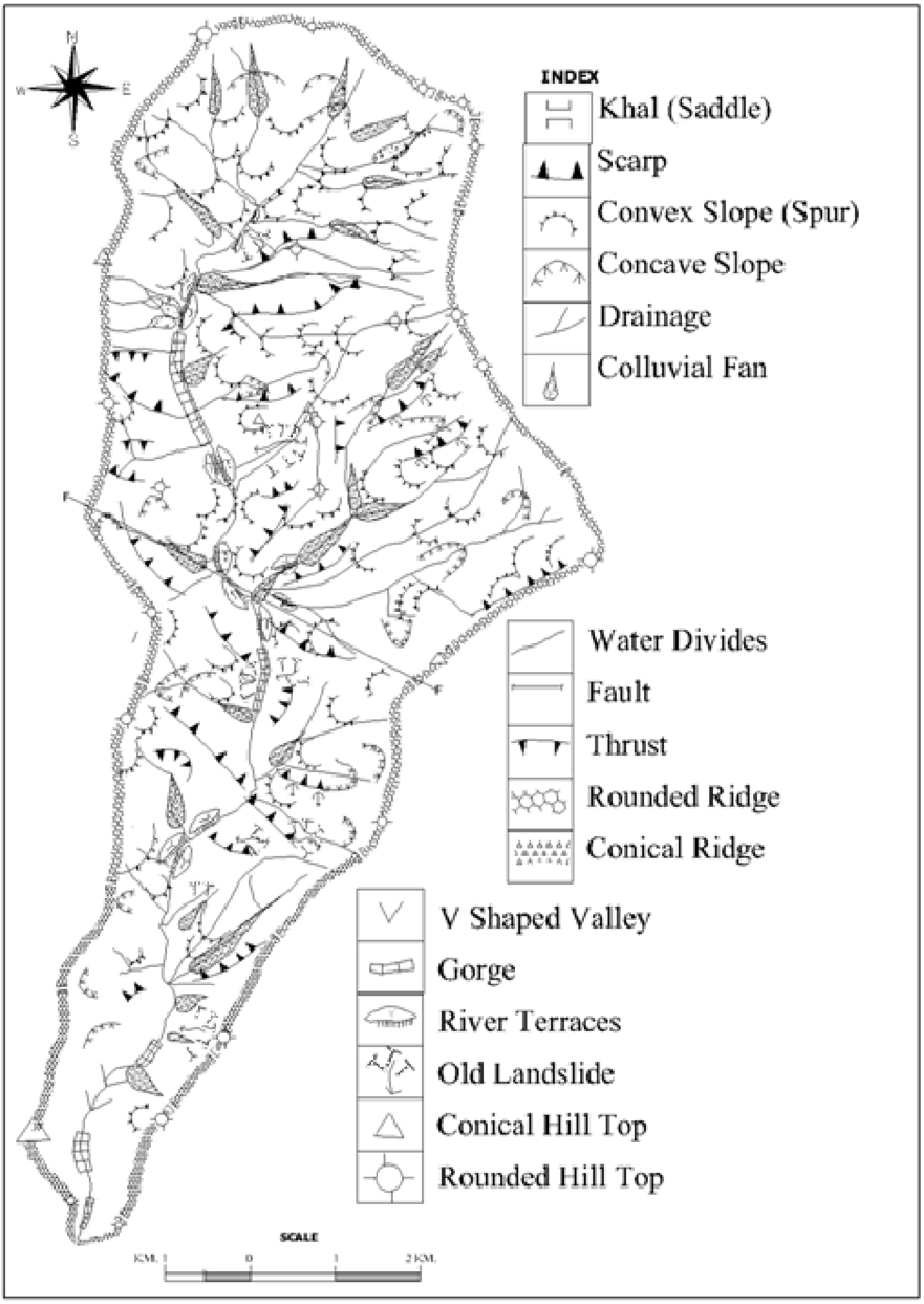

Fig. 3. Geomorphological map of Dhundsir Gad watersheds

valley. Slopes which receive maximum amounts of rainfall have more dense forest patches. Chir pine (*Pinusroxburghii*) is the dominant species extending up to 2100 m. Other important forest tree types of this area are *Maru, Kharsu, Oak*, Rhododendron, Silver Oak, Blue Pine, *Deodar* and Cyprus. The vegetation pattern in the watershed is quite similar to the broad pattern of vegetation zones of the northwestern Himalayas.

The economy of the local people is linked to and dependent on the surrounding forests from which they derive fuel wood, fodder, timber and minor forest products for their subsistence. In addition, people grow their own fodder trees to supplement requirements.

Sensitivity Analysis

The sensitivity analysis (Table 2) displays the susceptibility of each of the zones to different hazards and are rated as low, medium or high.

Table 2: Sensitivity of the three morphogenetic zones to environmental hazards

Altitudinal zone	*Low valley*	*Mid-valley*	*High range*
Landslide susceptibility	High	Low	Medium
Rock fall	Medium	Low	High
Slope failure	High	Low	Low
Flash flood	High	Medium	Low
Rainfall	Low	Medium	High
Cloud burst	Low	High	Medium
Soil depth	Low	Medium	Low
Soil edibility	High	Low	Low

Landslide susceptibility and rock falls are high and medium in the LV and medium and high in the HR respectively. The MV displays a low sensitivity to these parameters and therefore reflects a relatively safer place for people to live. The moderate rainfall levels in MV compared to that of LV and HR, as well as the low soil erodibility and slope failure parameters, further influence inhabitants to settle in this zone. The LV displays a high sensitivity to most of the param-

Source: www.googleearth.com T= Terraces

Fig. 4. River terraces at Dang village

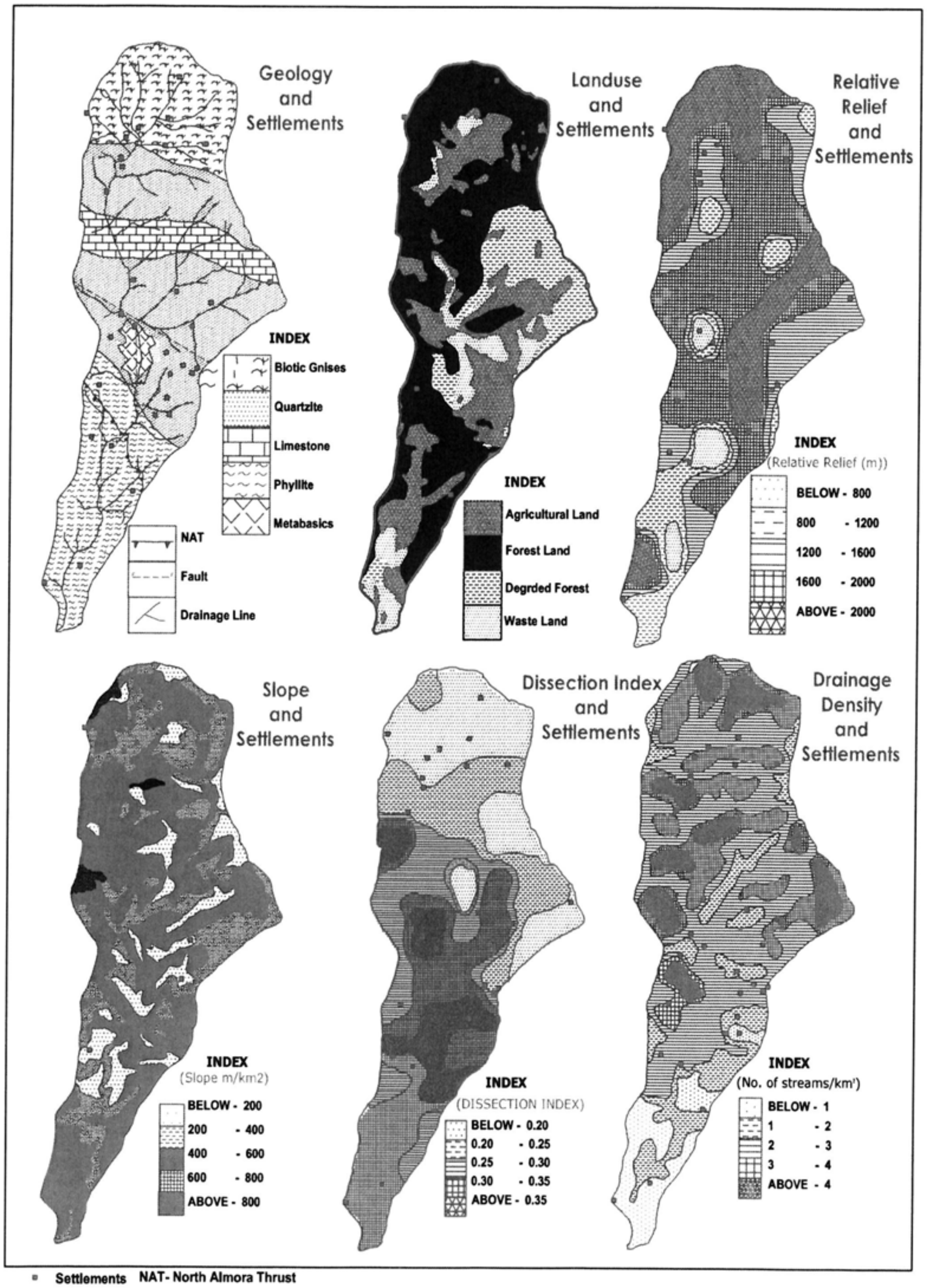

Fig. 5. Different morphometric attributes of the Dhundsir Gad settlements

eters with the HR showing a moderate sensitivity. All parameters in the sensitivity analysis depict the MV to be the most favourable zone to reside in with the exception of high sensitivity to cloud bursts and flash floods. Safety is a major influence in the location of settlements and this explains why the majority of settlements are located in the MV.

In this study, the classification of terrain units in terms of altitude also vividly expressed the rich geomorphic variation within different lithological units. Lithological variation along the Dhundsir Gad demonstrates a uniform pattern with phyllite terrain in the lower elevations followed successively by quartzite, limestone and, quartzite and biotite gneisses at the head of the catchment. The lithological arrangement presents a convenient base for relating morphological landscape characteristics to anthropogenic activities.

The mountainous Dhunsir Gad presents particular challenges for any settlement in terms of the many extremes that the natural environment presents. Through the field surveys, wide spectrums of geomorphological features were identified. Many of these are ephemeral, continuously changing features that preclude the safe establishment of settlements. These are particularly true of the LV region (9% of the settlements) whilst in the HR the adverse climate changes have similarly restricted settlements to just 9% of the total. The bulk of the settlements are located in the MV region which offers the comprise of a moderately affected zone for virtually all of the parameters investigated: climate, relief, slope, drainage density, drainage frequency and, accessibility to springs and forest resources.

CONCLUSION

The Dhunsir Gad valley displays an impressive array of morphological attributes that would have presented serious environmental forcing challenges to initial settlers of the region. Whilst no historical records of movements of dwellings exist, it is clear that over time, settlements in the MV region have gradually grown as more people recognized the relative advantages that the natural environment that this zone presented.

The detailed study of the morphometric attributes with settlement density indicates the relationship is not always linear. Whilst the economic benefits deriving from this location may not make it the obvious choice, other factors such as relative safety and ease of access to higher altitude grazing have swayed settlement location decisions in favour of the MV region.

This study shows that the distribution of settlements is very much affected by the morphometric attributes and physical environment in the Dhundsir region. The geological and geomorphic controls on settlements are more strikingly evident in the choice of settlement locations and in the availability of agricultural lands, such as with the case of the quartzite zone of the MV having dense settlements and more extensive agricultural land.

RECOMMENDATIONS

This study addresses the physical environmental factors that have influenced settlements choices as well as inhabitants perceptions of choice of settlements located in the Dhundsir Gad watershed of the Himalayas. It is one of the few studies addressing these relationships and it is recommended that such studies be extended over other regions of the Himalayas. Clearly, results from such efforts would impinge positively in the decisions for settlement expansion or the establishment of new settlements in the region and in other similar terrain.

ACKNOWLEDGEMENTS

The authors are grateful to Prof. Devi Datt Chauniyal, Department of Geography, H.N.B. Garhwal University, Srinagar Uttarakhand for his valuable input in this geomorphological study.

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